AN ANALYSIS OF THE RADIOGRAPHIC RELATIONSHIP BETWEEN MANDIBULAR LENGTH AND OCCIPITAL CONDYLAR HEIGHT

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INTRODUCTION

Man has always been fascinated by facial form and esthetics. From the beginning of recorded history, cave dwelling artists began to develop a concept of "normal" facial balance. Physical anthropologists were later able to quantify some of these proportions using skeletal remains and direct soft tissue measurement. The development of the Broadbent-Bolton cephalometer in 1931 introduced a standardized roentgenographic technique that was able to record these cranial landmarks in the living head.[1] Since that time, numerous analyses have been developed which relate these landmarks using normative data.

This information has been useful in documenting growth and treatment changes, and has been utilized to try to predict these changes. This has been troublesome since individual variation exceeds the estimated growth.[2] Growth prediction would be very helpful in planning orthodontic mechanics and treatment timing. The facial profile almost always becomes flatter with late mandibular growth.[3,4] Predicting the time and amount of growth would simplify the correction or maintenance of anterior-posterior relationships.

It has been proposed from clinical observation that in cases of mandibular "overgrowth", the occipital condyle is also larger than normal.[5] The major growth site on the mandible is the condyle. Since both the mandibular and occipital condyles are articular in nature and somewhat similar histologically, it is hypothesized that both may exhibit similar growth. The purpose of this investigation will be to compare the absolute length of the occipital condyle versus the mandible in a group of non-growing individuals with "large" mandibles and compare these to a control sample with "small" mandibles. A positive correlation would stimulate interest in further growth studies that would attempt to quantify and predict late mandiblar development.

REVIEW OF LITERATURE

"More is missed by not looking than by not knowing."

Thomas McCrae (1870-1935)

The observation that mandibular prognathism may be related to the vertical height of the occipital condyle has not been noted in an extensive review of the literature. The evidence for or against this supposition will be presented through several different although related fields: 1) a review of the quantitative data obtained through craniometry, anthropomietry and radiology; 2) a summary of mandibular growth prediction study and; 3) a discussion of anatomical, embryological, and histological considerations. Hopefully, this information will provide a premise for undertaking this project.

Man's fascination with facial profile and mandibular prognathism can be shown through his earliest artwork. Early drawings and sculpture showed wide variation in mandibular prominence.[6] Hippocrates[6] (460-357 B.C.) described both the size and shape of a large number of skull forms. However, he did not quantify these findings.

One of the first to utilize proportional measurements was Leondardo da Vinci[7] (1452-1519). His drawings often contained both horizontal and vertical lines used to divide the face and profile of his subjects.

The interest in facial balance and proportion continued until the eighteenth century. It was at that time that Pieter Camper[7] (1722-1789) made the first attempt at an actual metrical determination. He introduced Camper's angle in a paper published posthumously in 1791. This angle was formed by a line drawn through the ear hole and the nasal spine, and a second line joining the most prominent point on the forehead to the alveolar margin of the upper jaw. The major drawback to the use of Camper's facial angle was that it ignored the contribution made by the lower jaw to facial form. It was also found to vary considerably within race.[8]

Camper's angle was soon followed by numerous other horizontal lines and systems of analysis, some of which were later used to quantitate mandibular prognathism. The Frankfort plane, which is still widely used today, was introduced by Von Ihering in 1872. Others include cranial base planes connecting basion on the inferior border of the occipital condyle and nasion. These were useful in orientating the skulls in early craniostats.[7]

Prognathism was a term coined by Prichard in 1843 and in the study of craniometry usually refers to the prognathism of the upper jaw and teeth. This resulted from difficulty in orientating the mandible to the cranium and cranial base. Also, in some of the skeletal material it was difficult to be certain a given mandible belonged to a given skull.[9] There were, however, many methods used to determine the amount of mandibular prognathism. In general, angular measurements were preferred over linear since they allowed direct comparison between race.[7]

It was unfortunate that many of the workers in the eighteenth and nineteenth century were particularly interested in relating intelligence to cranial size. Although they gathered a large amount of data, it was not fully utilized to study mandibular growth and prognathism until the beginning of the twentieth century.[8] This information, although useful in an anthropologic perspective, was not nearly as meaningful as radiographic data which can be superimposed for growth studies. This particular information is abundant and will be discussed later.

The foundation for modern orthodontics was laid by E.H. Angle in The Treatment of Malocclusion of Teeth[10]. Angle classified occlusion in relation to the upper first molar which he stated was the "key to occlusion" and that "Nature exercises the greatest care in locating them... and so places them that the rest of the dental apparatus may be completed normally." He felt that the position of the maxillary denture was constant and that a Class III malocclusion was due to abnormal mandibular growth. Angle thought that "enlarged tonsils and the habit of protruding the mandible" caused abnormal muscle function resulting in the overgrowth of the mandible. Although his classification was strictly dental, Angle noted that the Class III occlusion produced "by far the worst type of deformities the orthodontist is called upon to treat, and when they have progressed... the case has usually passed beyond the boundaries of malocclusion only, and into the realm of bone deformities". Angle became convinced that in some Class III cases surgery would be necessary to improve "facial lines" and he proposed a double resection of the mandible.

During the 1920's Milo Hellman[11] conducted extensive research in Angle's classification using anthropometric methods. His work is often criticized for the variability in soft tissue measurement. Hellman felt that, "measuring individuals directly had an advantage over measuring complex curves of a three-dimensional object on a flat photograph or illusive shadows on a roentgenograph." By developing standard measurements he was able to show the high amount of normal variation and refute Angle's concept that a normal face was a result of normal occlusion. Hellman described the Class III relationship as "a relative one, i.e. while the lower teeth are anterior to the upper, it is not certain which of the two dental arches is in its normal antero-posterior position". He further stated that "the effect of Class III malocclusion on the face is not due to the occlusion of the teeth; but rather, the occlusion of the teeth, and the size of the jaw bone as well as that of the entire face, are determined by certain disturbances which interfere with balance and harmony in development".

Oppenheim[9] also used anthropometric methods to analyze the position of the upper first molar and found it to be quite variable. He also noted that mandibular growth was variable and independent of maxillary growth. From this he inferred that Class III malocclusion resulted from an overgrowth of the mandible in relation to a normal maxilla.

In contrast to the mandible, the paucity of information regarding the craniometric measurement of the occipital condyle is striking. Tobias[12], in his study of the occipital bone in Africans, briefly mentioned the differences in the shape of the condyle as a method of sex determination.

Guidotti[13] compared the inferior surface area of the occipital condyle with skull volume and found no significant correlation in 424 male and 317 female skulls. There was a significant sex difference ($p = .001$). The anterior-posterior length of the condyle was 23.7 mm S.D. 2.7 mm. in the males 22.3 mm S.D. 4.0 mm in the females. Guidotti observed great variability in the surface anatomy of each condyle, even in the same skull.

Olivier[14] has the most comprehensive study of the human occipital bone. Using 125 French occipital bone autopsy specimens he attempted to measure and correlate the growth of various parts. He used this information as evidence to show that the growth and development of the squama was independent of the pars basilaris.

Looking specifically at the conyle, Olivier measured the vertical height on a line perpendicular to the basion-opisthion plane. He also measured the length in a sagittal plane and the breadth in a frontal plane. The results of these measurements are shown in Table 1. The combined sample included a very small male skull and a very large female that were not included in the individual categories, presumably to increase the sexual dimorphism.

Correlating these dimensions, Olivier observed that the height was correlated only with the length ($p = .001$), and that the breadth and length were independent. Although the actual coefficients of correlation were not given a $r = 0.18$ was determined to be statistically significant. In relating the condyle to the rest of the occipital bone there were numerous positive correlations.

In reviewing the literature on human craniometrics, the vast majority of correlations were between $r = 0$ to $r = 0.6$. The few that were higher apparently were the result of a part-whole correlation.[2] Thus it may be reasonable to speculate that large heads may have statistically larger mandibles and occipital condyles. Nevertheless, to obtain a correlation in the predictive range ($r = 0.8$) would be unusual.

The use of radiographs to aid craniometry was first described by Pacine[15,16,17] in a series of articles in 1922. This was followed by Broadbent's[1] 1931 paper which described a standardized radiographic technique that enabled precise and repeatalbe lateral and frontal films to be taken. Broadbent[18] introduced the bolton-nasion plane as a stable base for orientation and registration of superimposed radiographs. He used this to document the normal downward and forward growth of the face and mandible in an orthodontically treated sample. This classic paper revolutionized the study of orthodontics and most of these concepts are still used today.

Following Broadbent, numerous investigators developed their own systems of analysis. Using different reference planes, angles, and points, they all developed norms that were used to document variation, record growth and treatment changes, and later to predict these changes. A complete review and critique of each analysis is beyond the scope of this project. Therefore, only the commonly used systems and their description of mandibular prognathism will be mentioned.

True mandibular prognathism is a skeletal discrepancy. It should be distinguished from a pseudoprognathism, which is an anterior shift of the mandible resulting from premature contact of the anterior teeth. Mandibular prognathism is usually associated with Class III malocclusion, but in some instances a prognathic appearance will occur in the absence of Class III molars. Conversely, a Class III relationship will not always result in mandibular prognathism.[2] The incidence of a Class III malocclusion with or without a skeletal discrepancy has been reported to be between one and 12.2 percent. Most studies reflected on incidence below five percent.[19]

In 1947 Bjork[3] published his thesis, <u>The Face in Profile</u>, for the purpose of analyzing the nature of prognathism, to determine the normal range of variation in the Swedish population, and to determine growth chnages. In it he described mandibular prognathism as a relative condition that could be attributed to one of several variables:

1) A large mandible relative to a normal maxilla
2) A small maxilla relative to a normal mandible
3) A normal maxilla positioned posteriorly relative to the cranial base
4) A normal mandible position anteriorly relative to the cranial base
5) A forward rotation of the mandible causing the chin button to move relatively forward.

Bjork utilized facial profilograms to illustrate these relationships resulted from changes in the size of the jaws, as well as decreases in the saddle angle and length of the cranial base. These concepts will be discussed in more detail later.

The results of Bjork's study came from a first sample of 322 Swedish boys past the age of 12 but not yet 13. His second sample included 281 Swedish conscripts past the age of 21 but not 23. He analyzed numerous angular as well as linear measurements. Many of these became integral parts of subsequent cephalometric systems. He noted that the profile became flatter with relatively greater mandibular growth. The mean mandibular length of the conscript group measured from articulare to the most prominent point of the chin was found to be 118.45 mm S.D. 6.28 S.E.M. 0.37 mm.

In 1947, Wylie[20] presented An Assessment of Anteroposterior Dysplasia. Using linear measurements obtained from an 11.5 year old male and female sample, he established means for components of maxillary length as well as mandibular length measured parallel to the mandibular plane. From these values it was possible to analyze the degree of prognathism and also localize these areas of dysplasia.

One year later, in 1948, Downs[21] presented his classic paper introducing the analysis which bears his name. His purpose was "to determine the range of the facial and dental pattern within which one might expect to find the normal". His sample consisted of 10 boys and 10 girls between the ages of 12 to 17, and with clinically excellent occlusions. He felt there was an average facial pattern for individuals possessing excellent occlusions. He felt there was an average facial pattern for individuals possessing excellent occlusions and that the "skeletal pattern in the lateral aspect may be described in figures and be appraised as good or bad according to the amount of deviation of the readings from the known mean pattern".

The Down's analysis consisted of nine angular and one linear measurement. He used the Frankfort horizontal as a reference plane because he felt it "cut across the face and hence would be a more logical choice for a study of a relationships involving only the face". The three angles used to describe the degrees of prognathism were the facial angle, the angle of convexity, and the AB plane to facial plane. Downs also used the Y axis to show the direction of mandibular growth.

Although these angles had been previously described, the elegance of Down's article was shown by its acceptance then, and its continued use today. Subsequent authors presented their own systems which were used to evaluate prognathism in essentially the same manner as Downs.

During the 1940's, Tweed[22] became the leader of the extraction movement. Although his analysis had little to do with documenting mandibular prognathism, it did bring cephalomtrics into daily clinical practice. Using the mandible and Frankfort horizontal as planes of reference, Tweed attempted to improve facial balance by placing the lower incisors "over basal bone", often at the expense of four first premolars.

Riedal[23] introduced the SNA, SNB and ANB angles in his thesis presented in 1948. He used these to determine the constance or variation in the relation of maxilla to cranium and mandible. For his sample of 52 adults with excellent occlusions, he obtained a mean SNA of 82.0° S.D. 3.89° , a mean SNB of 79.97° S.D. 3.60° , and a mean ANB of 2.04° S.D. 1.81° . He compared these values to be a Class III sample of nine individuals.

Alhtough this was too small to be tested statistically, he noted that in general the mean SNA angle was similar to the excellent occlusion sample, whereas the SNB angle was noticeably larger. When comparing this finding to a sample of 24 children he presented evidence that the mandible had a tendency to become more prognathic with growth.

In 1953, Steiner[24] published his analysis which established treatment objectives for the incisor teeth in response to differences in the SNA and SNB angles. His analysis was quite comprehensive including an interesting evaluation of mandibular length. He projected a point L from pogonion to SNB and a point E from the posterior condyle to SN. The measurement of L to E gave an estimate of relative mandibular prognathism.

Sassouni[25] proposed his archial analysis in 1958. To avoid the individual variation seen in a single plane of reference, Sassouni used several planes to located a point of divergence; point 0. From this point, usually located behind the head, he was able to construct arcs that illustrated the relative amount of mandibular prognathism. He felt an analysis based on geometrical proportion was more likely to be clearly understood and more meaningful than one in which it was necessary to struggle with numbers.

The "Wits" analysis was developed by Jacobsen[26] in 1975 as a diagnostic aid to determine the degree of anteroposterior jaw disharmony. Jacobsen tried to avoid relating the jaws to cranial reference planes, which he felt presented inherent inconsistencies because of variation in craniofacial physiognomy. The method entailed drawing perpendicular lines from point A and B to the occlusal plane. In a sample of 21 male and 25 female adults with excellent occlusion, he found the perpendicular coincided in females and B point was 1mm anterior to A point in males.

McNamara[27] developed his cephalometric system in the 1980's to better show alterations in craniofacial structure obtained through surgery and functional appliance wear. Although a rehash of older systems, it did provide numerous angular and linear measurements to show mandibular prognathism. The mean mandibular length measured from condylion to gnathion was calculated for three different samples as shown in Table II. It was noteworthy to quantitative the relative amount of late mandibular growth. McNamara's analysis has become popular in some areas of the country and thus is useful for communication purposes.

Other measurements of mandibular length in adults have come from the Iowa growth studies. Bishara[28] found the mean mandibular length measured from articulare to pogonion for an adult sample with a mean age of 25.5 years was 115.8 mm S.D. 6.5 mm for 20 males and 102.4 mm S.D. 4.5 mm for 15 females. This study also showed significant growth in males and females beyond the age of 15.

In utilizing the common systems of cephalometric analysis to understand mandibular prognathism many of the concepts were intially described by Bjork[3] in 1947. In 1955 Sanborn[29] presented a comprehensive article on Class III malocclusions which supported Bjork's original classification system, listed previously. Sanborn found that 45.24% of his Class III sample had mandibular prognathism with the maxilla in a normal range. In 33.33% there was maxillary retrusion and a normal mandible. In 9.5% the maxilla and mandible were in a normal range, and in 9.5% there was a combination of maxillary retrusion and mandibular prognathism.

Dietrich[30] undertook a similar study in 1970 and found 37.5% of his Class III sample to have maxillary retrusion and a normal mandible, while 31% had mandibular protrusion with a normal maxilla. In 24% both maxilla and mandible were within normal range. In 6% there was both maxillary and mandibular retrusion, while 1.5% have maxillary retrusion combined with mandibular prognathism.

Dietrich further divided his Class III sample into a deciduous, mixed and permanent dentition group. He compared these to a Class I sample divided into similar groups. He reported that in almost half of the deciduous Class III sample both the maxilla and mandible were in a normal range, whereas only one-fourth of the mixed and permanent sample had this condition. This indicated that the Class III skeletal discrepancy worsened with age.

In 1974, Jacobsen[19] published his classic article on the Class III malocclusion. Measuring the SNA and SNB angles of 149 patients with a Class III discrepancy Jacobsen compared these to Steiner's normal range for these values at 1 S.D. He noted that in 40.63% of the males and 55% of the females the maxilla was in a normal range of prognathism while the mandible was beyond. In 28.12% of the males and 23.53% of the females the maxilla was below the normal range and the mandible was normal. In 21.87% of the males and 5.58% of the females the maxilla and mandible were both within the normal range. Finally, in 6.25% of the males and 5.88% of the females the maxilla was below the normal range and the mandible was above the normal range. When compared to a Class I sample the angle SNA was found to be slightly, but nevertheless significantly smaller in the Class III sample, while the angle SNB was much larger. Sanborn[29] reported the same findings in his sample of 26 adult males and 16 adult females. Horowitz[31], using multivariate analysis also reported similar results in a combined sample of 52 adults. Conversely, Stapf[32] found no significant differences in the angle SNA, but did report a significant difference in the angle SNB. Koski[33] also found no significant difference in the angle SNA and summarized that in general, Class III malocclusions result from a protrusive mandible in relation to a normal or slightly retrusive maxilla.

Jacobsen[19], Sanborn[29], and Horowitz[31], found the longer effective total mandibular length was due to a more obtuse gonial angle. This was also reported by Koski[34] who felt it was because the ramus acted as an adjusting link between the tooth-bearing corpus and the articulating condyles of the mandible. It confirmed that the difference in length of Class III mandibles may not be due so much to size, but, rather, to morphology.

When Jacobsen[19] compared his adult sample to 30 male and 53 female children ranging in age from 6 to 16 years old he found a "burgeoning growth of Class III mandible". This had the effect of producing the greater proportion of adults in the category in which the mandible had developed beyond the range of normal prognathism. Tweed[35] supported this concept in his discussion of Class III etiology Jacobsen felt that once the prognathism proceeded to an ANB angle of -3.5 or less, surgery was necessary to correct the malocclusion.

Bjork[36] has contended that a short cranial base and an acute saddle angle may be responsible for some cases of mandibular prognathism. This idea has also been supported by other studies[23,29,30,31,32,37]. Although Bjork has noted this was a rather loose relationship, Ruhland has stated there was a high correlation. Koski[33], on the other hand, has argued that there was no relationship. Using angle NSBa instead of the usual NSAr, he did not find any significant correlations with mandibular length or protrusion. He argued that articulare was an artificial point, that its location was determined by the condyle, and that it was not in the same plane as the commonly used indicators of prognathism, SNA or SNB. Furthermore, he felt some degree of correlation was to be expected since both angles shared one leg.

Guyer[37], et al. has just recently published a cross-sectional study of 144 Class III subjects ranging in age from 5 to 15 years old. Utilizing a digitized x-y coordinate system and computerized analysis, he was able to compare his sample to a Class I longitudinal sample of 16 males and 16 females from the Bolton study. He noted many similarities to the previous work of others.

Specifically, he observed the posterior cranial base from sella to basion was significantly longer in the Class III sample. He showed the maxilla in the Class III group to be significantly shorter in both absolute and effective length. The mandible was found to be significantly more prognathic and longer by 3 to 6 mm when measured from condylion to gnathion. He also noted the gonial angle to be significantly more obtuse and anteriorly positioned in the Class III subjects. Finally, when analyzing the different age groups he found a strong tendency for the early appearance of these characteristics.

The development of cephalometrics has been very beneficial to the student of orthodontics for the study of growth and individual variation. It has been useful in documenting treatment changes and as a communication tool. Specifically, it has been used to show the normal range of mandibular prognathism and its development. The prediction of these changes will be discussed shortly.

In spite of the fact that there have been no radiological studies which have directly measured the height of the occipital condyle. There have been a wealth of studies which have measured other structures in the cervical area. This is because hyperplasia of the occipital condyle is very rare and normally would not cause any problems. Conversely, underdevelopment of the condyle may lead to a group of anomalies collectively called basilar impressions[38].

Hinck[39] defined basilar impression (or basilar invagination) to be, "a deformity of the osseous structures at the base of the skull in the region of the foramen magnum. The periforminal components of the occipital bone, and later the petrous portion of the temporal bones, are invaginated upward in such a manner as to diminish the volume of the posterior cranial fossa. Because of the relative immobility of the tentorium cerebelli above, there may result compression of the contents of the posterior fossa and the high cervical spinal cord, embarrassment of circulation, or impairment of the flow of cerebrospinal fluid".

Basilar impression may be congenital or acquired. The symptoms are variable and it is often mistaken for other central nervous system disorders, such as multiple sclerosis. Because of this, diagnosis is usually based upon radiologic evidence.[40] McGregor[41] presented a comprehensive review of the methods for diagnosing basilar impression. Three of these methods are now commonly being used on lateral headplates and have provided indirect evidence about the size of the occipital condyle.

McRae's[41] line is not an actual measurement but it is the most commonly used method to detect basilar impression. It is often referred to as the foramen magnum line because it connects basion to opisthion (Figure 1). Basilar impression should be suspected if the occipital squama is convex upward or if it lies above this line. Normally the tip of the dens does not exceed it.

McGregor's[40] base line joins the posterior edge of the hard palate with the lowest point of the occipital squama (Figure 2). It is used in a similar fashion as McRae's line, with basilar impression to be suspected if the tip of the dens is more than 5 mm above the line. It has been criticized for using facial structures to define a cranial base area.

The height index of Klaus[40] is defined as the distance between the tip of the dens and the tuberulo-cruciate line which connects the sella tuberle to the cruciform eminence of the internal occipital protruberance (Figure 3). This distance averages between 40-41 mm in adults. When it is between 30-36 mm pathology is possible and below 30 mm is diagnostic for basilar impression.

These reference lines are commonly used in radiologic surveys of the upper cervical spine. Although they do not give any quantitative data on the height of the occipital condyle, they do give indirect evidence of its development. In most cases of basilar impression, the condyles are hypoplastic and certainly a large space may indicate larger condyles[40]. Since basilar impression often is asymptomatic, it may be useful to utilize these measurements on routine surveys of orthodontic lateral radiographs.

In response to "What has cephalometrics contributed to mankind?", Hixon[42] replied, "It has humanized the orthodontist." He further stated that "In cephalometrics, this is manifest by the gradual recognition of the normal variability among people, the variability in the way people grow, and our inability to accurately predict this variability for any single human organism." The history of attempting to predict mandibular growth has always held promise as an aid in treatment planning, treatment timing, and prevention of relapse, and promising it remains. With this purpose in mind, the present paper will make another attempt at breaking the null hypothesis for predictive purposes.

In the early history of modern orthodontics, the teaching of Angle[10] refuted the need for growth prediction. The development of mandibular prognathism was merely a result of abnormal environmental influence on "the Great Watchmaker's" plan. By diagnosing and eliminating these factors early, normal occlusion would lead to normal function and consequently normal development. In defense of Angle, there was very little evolutionary or genetic evidence to support the concept of individual variation.

The development of a standardized roentgenographic technique[1,18] aided Brodie[43] in his study of the growth pattern of the human head from age three months to eight years. He concluded that facial growth was stable from early in life and that it occurred primarily along straight lines in an orderly and uniform manner. If this supposition was correct, then the prediction of growth direction would merely involve finding stable reference planes.

This concept was the basis of Down's[21] Y axis, which became the first widely used method of predicting mandibular growth direction. While providing the orthodontist with a perception of cranial growth, it became apparent clinically that the Y axis was lacking in its ability to predict the magnitude and direction of mandibular development.

The variability of this pattern was clearly exemplified by Bjork's[44,45] classic work utilizing metallic implants as stable reference points. He demonstrated that in 45 Danish boys the anterior aspect of the chin underwent, for the most part, no visible remodeling. The most pronounced remodeling was shown to occur in the angle and lower border of the mandible. This area usually exhibited resorption, but apposition was seen occasionally. He further noted that the majority of growth occurred in the condylar region and that there was appreciable variation in the direction and magnitude of this growth. By constructing the average direction of condylar growth in relation to the posterior tangent of the ramus on the original radiograph, Bjork formulated the concept of anterior and posterior rotation. He noted that the condyle usually grew slightly forward of the ramus resulting in a forward rotation, but there was found to be a range of almost 45° , with some mandibles rotating backwards.

Bjork[46] used longitudinal data (4 to 24 years) on a mixed sample of 100 children to attempt the prediction of this rotation. He noted that predicting shape with the use of superimposed radiographs was futile because the pattern of growth was not constant. He also stated that predicting facial development from a single radiograph using any type of metrical measurement had not been fruitful. Instead, Bjork listed seven structural signs that may be used to warn the clinician of an extreme backward or forward rotation. Although the validity of this method has been seriously questioned by Baumrind[47], the study did provide useful superimposition landmarks on the inner cortical surface of the symphysis, the mandibular canal and the third molar germ.

Bjork's studies were perhaps the most important contribution to the understanding of mandibular growth, however, the findings demonstrated the difficulties encountered in predicting these changes. The realization that the mandible grew in different amounts and changing directions stimulated new efforts to predict these variables. These methods have become increasingly more sophisticated, yet none have been able to decipher individual genetic variation.

Moss[48] has hypothesized that this variation is a product of functional matrices. The mandibular matrix consists of all related soft tissue and the mandible develops within the function of that matrix. The mandibular condylar cartilage consitutes only a secondary, compensatory growth site. Moss[49] has suggested that the genetic determinant of matrix growth may be controlled by the development of the central nervous system. Through his study of the alignment of the fifth cranial nerve foramina, Moss has suggested a logarithmic spiral as a pattern of mandibular growth.

Ricketts[50] used cross-sectional data to elaborate a mathematical technique to express the arcial growth noted by Bjork and Moss. By trial and error, he was able to construct an arc of a circle which, "when extended and properly located, will permit the clinical projecting or forecasting of the natural growth of the normal mandible well within the desirable clinical limits of accuracy". He did note that this method "did not seem to be directly applicable to patients with true mandibular prognathism, but must be modified for that specific situation". His concept of separating normal growth from pathological growth was quite similar to Angle's avoidance of accepting normal individual variation.

Ricketts[51] has attempted to solve (and complicate) this dilemma with the use of computers. By utilizing before and after treatment records he has developed a cephalometric analysis that has been used to predict treatment and short range growth changes. This analysis uses numerous "measurements to quantitate stress systems and architectural patterns." By correlating a number of these values, Ricketts felt he was able to predict variation or at least warn the clinician of potential abnormal mandibular development. Using longitudinal material, Ricketts has also attempted to forecast long range growth changes.

These systems are available commercially and have become the most popular method of computerized mandibular growth prediction. Because of their popularity and dubious validity, statistical evlauation of their results have been attempted. Greenberg and Johnston[52], evaluating 20 untreated patients, reported that the commercial forecasts were no more accurate than adding mean changes obtained from independent samples.

Schulhof and Bagha[53] examined the longitudinal records of 50 untreated cases and compared Rickett's computerized method to merely adding mean annual increments. He concluded that the refined computer methods will not be markedly more accurate in 70% of the patients in the normal range of mandibular growth, but will show considerable advantage in 30% of the abnormal patterns, including Class III tendencies.

Schulhof and associates[54] studied a series of patients that grew far differently from the computerized prediction. These patients grew less in the cranial base and more in the mandible, developing a Class III malocclusion. By making a composite of these subjects, four factors were identified that made it possible to distinguish between "normal" and "abnormal" growth. After examining a group of Class III Japanese, Schulhof demonstrated that the abnormal group could be identified in most cases.

In summarizing Rickett's work, there seems to be a lack of hard evidence to substantiate his methodology. However, before starting a more generalized critique on mandibular growth prediction, it is important to stress Rickett's contributions to this field. His studies have been the forerunner for all subsequent techniques. Whether discussing mesh diagrams[55], grids[56], mandibular morphology[46] or indeed arcial growth, all have attempted to predict human variation. While their success in doing this has been questioned, they have all contributed to the understanding of normal mandibular development.

It has been pointed out by Greenberg[52] that the practice of growth prediction, according to any of the published methods, is actually pattern extension. Ricketts[56] has evolved into this concept changing his individual "dynamic synthesis" into a "mean-change expansion". Pattern extension involves the addition of mean increments along existing directions of growth as exhibited by the initial facial pattern. Hence, if two patients were of the same age, sex, and race, a prediction of future growth would merely involve adding the same increments to both individuals. Conversely, a true prediction would involve forecasting a change in direction or a different growth rate based upon unique cephalometric measurements. Johnston[57] has raised several objections to the variables, Ricketts has used to obtain his prediction:

1. There is little evidence as to the exact significance of each of the many variables employed.
2. There is little reason to believe that these numerous variables are not, to a greater or lesser extent, redundant. (10 are obtained from the mandible alone.)
3. There are no objective rules available for the use of these variables.
4. Estimates of confidence intervals or of prediction efficiency for a consecutive, nonorthodontic series are not available.

Greenberg[52] has noted that long-term forecasts gain their individuality, not from a capacity to predict the way a child will grow, but rather from the fact that a variety of constants are added to the dimensions of a subject that has almost gained adult size. Hixon[52] has referred to this pitfall as the part-whole correlation. He argued that since a child old enough to be treated orthodontically has facial dimensions which are 80 to 90% of their adult size, it would be more appropriate to correlate incremental growth with initial facial dimensions, rather than absolute size. Hixon[42] concluded that "the best estimate of any individual adult facial dental arch dimension is to use the dimension presented by the child and to add to that the remaining average growth for the group". Since the variation in growth after age 12 is approximately 50% of the total variation between adults, the addition of average growth changes onto the existing facial pattern will contain half as much error as predicting individual adult dimensions with the use of cephalometric norms[42].

Although computer programs may not be able to predict individual variation, it has been argued that they offer the clinician a visualization of the most probable pattern of growth[51]. Specifically, it has been suggested that they would offer a "blueprint" for the initial stages of treatment. Others[57,58] have noted that in view of its modest statistical value, simpler (and less costly) methods could be utilized. Johnston[59] has developed a grid system on which to add mean changes. Balbach[60] used simple correlations and multiple regression to test the significance of various measurements of mandibular morphology at age seven with the occlusal position of the mandible at age 11. In evaluating the predictive significance of these relationships he concluded that, "The addition of mean increments of change to the existing position of a mandible proved to be a simple and fairly efficient method of predicting the future position of the mandible". Although he found complex multiple regression equations (similar to a computer's) were statistically more efficient, the differences in predicting efficiency was clinically negligible.

A further complication to mandibular growth prediction, especially short range prediction is the problem of reliability. This concern was first attacked by Bjork[3] nearly 40 years ago. Bjork felt that in general, his work had a measurement error of less than 0.5 mm.

In 1966, Richardson[61] examined the reproducability of points, planes, and lines on lateral cephalometric radiographs and one week later the same procedure was repeated. He found that some landmarks would be located with a greater degree of accuracy than others. He also noted that the direction of error vertically or horizontally was dependent upon the landmark in question.

A more sophisticated version of this study was done in 1971 by Baumrind and Frantz[62,63]. In their study, five different examiners located landmarks on 20 different lateral cephalometric headfilms. This data was then analyzed by a computer. They found that landmarks, lines, planes, or angles all had a range of error that was individually unique. Some of these measurements could be reproduced quite accurately while others had a considerable range of error.

Hixon[42] has observed that even with standard errors of measurement of 5 to 6% of the distance measured, a 1 or 2 mm error can result, which would be the same order of magnitude as the annual growth change. He concludes, "In other words, a dull tracing pencil can almost obscure a years growth".

A final complication to predicting growth is the potential effects of treatment. Ricketts[56] reported changes up to 8.0 mm in the antero-posterior position of A point. This far exceeds any growth changes in this area. Failure to account for these chnages would drastically lower the predictive ability. However, the ability to estimate treatment effects in advance would help to improve the accuracy of any system.

The ability to predict mandibular growth would be very beneficial to the clincian. Numerous studies show that the mandible matures later than the rest of the facial complex, resulting in a straighter profile[3,19,36,37]. Hixon[2] has stated that although there is an increase in size, facial proportions show little change on the average except for this increase in mandibular prominence. Because of its importance the prediction of mandibular growth has been studied extensively in three different ways.

The first has been to use the size at one age to predict the amount of future growth. Bjork[64] measured the length of the mandible at 12 and compared this to subsequent growth from 12 to 20, finding a correlation of $r = -0.09$. Harvold[65] measured mandibular size at age six and found a correlation of $r = 0.10$ at age nine. Meredith[66] found a correlation of $r = 0.04$ when comparing mandibular size at age nine to that at age 14.

Balbock[60] compared a number of mandibular dimensions at age seven and compared these to mandibular length measured from sella to gnathian and Y axis at 11. He found all correlations to be $r < 0.3$. Specifically, mandibular growth was $r = 0.27$ and Y axis change $r = 0.15$. Because of the extreme individual variation the correlation coefficient for any dimension when related to future growth will be between $r = o$ and $r = 0.4$[2] when comparing angular measurements Lande[4] has found a correlation between $r = -0.3$ to $+0.3$.

A second method which has been used to predict growth has been to observe growth for a period of time and use this amount to predict future growth. Harvold[65] measured mandibular growth from six to 12. Meredith[66] observed a mixed sample for five to eight years old and found the correlation in mandibular growth to be $r = 0.54$ in eight to 11 year old boys and $r = 0.39$ in eight to 11 year old girls. In reviewing Meredith's findings, none rose above $r = 0.5$. It should be emphasized that with this method using a broad age span will raise the correlation by lowering the amount of variation seen yearly.

Finally, a third method is to compare the growth rates of different facial dimensions. In measuring the velocity of mandibular growth in great detail, Meredith[66] found the highest correlation in boys between the ages of five and 10 years of age to be $r = 0.44$ (with nose width). The next highest correlation in mandibular growth velocity was $r = 0.43$ when comparing mandibular width to length. The correlations were dispersed between $r = 0$ to $r = 0.95$, with 50% of them not exceeding $r = 0.35$. This method presumes that facial growth velocity is uniformly constant. This concept is supported by the fact that linear correlations are usually positive, indicating that at least no dimensions get smaller with development. Meredith's[67] research also indicates that growth rates of different parts of the body can vary drastically. The relatively low correlations of mandibular growth velocity with other facial parameters is due to its late and relatively greater growth. When compared to other parts of the face, the possibility of "flagging" this growth by observing a large occipital condyle will be discussed in the final section of this paper.

It has previously been shown that a Class III occlusion differs significantly from a Class I occlusion in a number of cephalometric dimensions[3,19,23,29,30,31,32]. Guyer[37] has further shown that these differences result in a mean pattern that can be detected early in growth. Specifically, it has been demonstrated that Class III individuals have on the average longer (condylon to gnathion) and more prognathic (SNB) mandibles. As a first step in attempting to predict this growth, the present study will determine if there is a significant difference in the height of the occipital condyles between a Class II and III non-growing sample. If these values are significant, the length of the condyle will then be correlated with mandibular length, perhaps culminating a regression curve. To be clinically useful, further research would be necessary to quantitate these changes in a growing sample.

The obvious pitfall to such a project is that large heads will likely have large mandibles and large occipital condyles. In spite of this part-whole relationship, to obtain a correlation in the predictive range $r = 0.8$ would be interesting. If this is the case, further research on growth velocity would be justified.

Koski[34] has stated that "the variability of the growing facial skeleton renders any rigid use of the relationship between various fixed points, planes and angles in diagnosis and prognosis or in the classification of facial types of little value except as an exercise in geometry". Hixon has summarized that the principles which govern growth, "are not and cannot be well described by a cephalometric analysis", rather, "a search for the biologic principles would be more rewarding". The final portion of this paper will attempt to examine the biological relationship between the mandible and the occipital condyle.

The amount of current research using the classic methods of mandibular growth prediction is surprising when considering the almost complete lack of success. Almost fifteen years ago Hixon[42] stated that "the future of cephalometrics is that the clinician will continue to try to use cephalometrics for predictive purposes for another generation or so in the name of security, motherhood and the archangels". Clearly, the time is past for orthodontics to put aside these traditional methods and explore new avenues of growth research. Although the present study utilizes these older techniques for quantification, it will attempt to base these measurements on biological principles. It could be argued that this is nothing unique. Nevertheless, it would seem more appropriate than the random search for cephalometric correlations.

The last portion of this paper will attempt to provide anatomic, histologic and embryologic evidence to support the contention that a large occipital condyle may indicate the potential for an "overgrown" mandible. By studying the similarities in the structures and tissues of the mandibular and occipital condyle, a biologic basis for this hypothesis will be developed. This will be followed by embryologic and growth findings that will elaborate how a large occipital condyle may potentially be used to predict, or at least warn the clinician of a large mandible.

The mandible articulates with the cranium through a true compound synovial joint; the temporomandibular joint. A typical compound synovial joint is composed of two bones covered by articular (usually hyaline) cartilage, which are separated by a fibrous articular disc and enclosed in a fibrous capsule containing synovial fluid. The temporomandibular joint differs from the average compound synovial joint by allowing both rotary, lateral, and gliding movements.[68]

The mandibular condyle has been shown to be the major site if not center of late mandibular growth[69,70]. However, unlike other growth cartilage the mandibular condyle has its articular surface and cartilage replacement tissue juxtaposed, rather than separate by epiphyseal bone. The outer surface is comprised of a fibrous cartilage. Immediately subjacent to this outer layer is a zone of mensenchymal cells capable of two functions. First, they can separate the constituents of the overlying fibrocartilage layer, and second, they can differentiate into cartilage cells to replenish those that are sacrificed in the conversion to bone, a process that occurs in the opposite direction[71].

In the condyle, a replacement mechanism is operating during growth that differs from other areas both in the source of new cartilage cells and in the orientation they assume the new cartilage cells are derived from noncartilage precursers; in all other replacement mechanisms they come from other cartilage cells. These cells remain haphazard, random, or embryonic and do not form the columnar arrangement seen in typical grwoth plates[72].

This unorganized anatomical arrangement has been used as evidence that the mandibular condyle is only a growth site. Other research tends to confirm this. The condyles are less sensitive to hormone and vitamen deficiency than growth plates. They are more responsive to mechanical stimuli; pressure diminishes cell activity, while relief from pressure promotes it. Transplanted mandibular articular cartilage do not seem to maintain themselves whereas epiphyseal cartilage does quite well. Finally, condylectomies in laboratory animals and young human patients have been found to affect the mandibular ramus only[73]. Conversely, Koski[74] has pointed out that to view cartilage of the face as "totally passive adaptive elements in all sites at all times would be equally one-sided and erroneous". He suggests that the cartilage of the race plays a complex role in integrating facial growth.

The occipital condyles are attached to the first and second vertebrae by strong ligamentous connections. The condyles articulate with the superior articular surfaces of the lateral masses of the atlas. The joint cavities of the atlas and axis communicate with the occipital condyles. The atlanto-occipital joint permits flexion and extension, while the more complex atlantoaxial articulation affords flexion, extension, rotation, vertical approximation and lateral gliding movements. These articulations are all true synovial joints which differ from the rest of the spine below the second vertebrae in that they lack intervertebral discs[75].

These discs are necessary to absorb shock to the vertebral bodies. Normally each disc is separated from the cancellous bone of the body by a plate of hyaline cartilage which in the child fits over the body of the vertebrae as an epiphysis. Because of the complex movement necessary in the upper cervical spine, the occipital condyles and first two cervical vertebrae are covered by hyaline cartilage only[68]. This arrangement is similar to that seen in the mandibular condyle. The exact nature of the endochondral ossification taking place in the occipital condyles appears to be more irregular than that seen in growth cartilage. Tillman and Lorenz[75] have further noted that these articular surfaces can possibly be transformed by mechanical forces during postnatal life. A specific histologic study of the occipital condyle is lacking but the complex nature of its function gives it a form similar to the mandibular condyle. Further research is necessary to determine the specific histologic interraction taking place.

The embryology of the occipital condyle is more clearly described. The occipital bone develops from seven ossification centers. Two of these form the supranuchal squamous part by intramembranous ossification. Below the superior nuchal line, the rest of the squamous portion ossifies endochondrally from two centers. The occipital condyles are formed from the single basilar part which appears at about the 11th week i.u. This part forms the anterior boundary of the foramen magnum and small anterior portions of the occipital condyles. The final pair of ossification centers appear at 12 weeks i.u. and are endochondral. They form the lateral boundaries of the foramen magnum and the major posterior portions of the occipital condyles.

The two portions of each occipital condyle exist in the neonatal skull separated by a cartilage free strip called the synchondrosis intraoccipitalis anterior. Ossification commences by the age of three or four and is complete by seven or eight.[77] Tillman and Lorenz have shown this division is not related to clefts which develop in about 5% of adult occipital condyles.[78] It should be emphasized that the entire occipital bone is usually ossified by seven or eight whereas the vertebral bodies are not completely fused until puberty. The remaining growth that occurs at the occipital condyle is appositional; similar to the mandible.[78]

The occipital bone as the other bones of the cranial base begin their existence as cartilage. During embryologic development, areas around the notochord begin to chondrify, and eventually most of the occiptal, temporalis, sphenoid, nasal area, and ethomoids are aggregated into a cartilagenous complex called chondrocranium. At birth, most of this cartilage has been converted into bone. What remains is demarcated by sutures. Two prominent exceptions to the complete postnatal elimination of cartilage are the spheno-occipital synchondrosis and the nasal cartilage.[71]

The mandible is an intramembranous bone which is derived from the first brachial arch. It develops lateral to Meckel's cartilage, which only makes a small contribution to the mandible proper. A single ossification center appears in each half of the mandible at six week i.u. This initial separation of the mandible symphysis menti is gradually eliminated by ossification between the 4th and 12th month postnatally.[71]

The cartilage that is found in the condyle is derived from mesenchymal cells unrelated to the first brachial arch (Meckel's) or the chondrocranium. Because of this it is often referred to as secondary cartilage. This cartilage appears during the 10th week i.u. and by the 14th week i.u. endochondral bone formation has begun. Much of this cartilage is replaced with bone by the middle of fetal life, but its upper end persists into adulthood.[75] While growth at the condylar cartilage normally ceases at about 20, the continued presence of the cartilage provides a potential for growth.[79]

This potential is seen in adulthood as acromegaly. In about 80% of the cases it results from an eosinophilic ademona of the pituitary gland. In most cases, there is enlargement and erosion of the sella caused by increasing pressure of the hyperplastic pituitary. It is characterized by growth changes seen in the bones and joints of normally non-growing individuals. These facial changes include gross thickening of the face and nose, prominence of the jaws, narrowing of the palpebral fissures, and in most cases, prognathism.[75]

The accelerated growth is due to excess growth hormone. When this occurs before puberty, gigantism results. After the epiphyseal cartilages are united endochondral growth continues in the mandibular condyle. Lang[80] reviewed 31 acromegallics and found only two to have no degenerative changes in sella. He also found occipital overgrowth in the form of spur like hyperostosis in 12 of the patients. The mandible was not studied in this series because most of the radiographs did not show it adequately.

Gilmore[81] had similar findings in his review of acromegally. He noted that the condition was associated with overgrowth of the mandible as well as degenerative changes in sella. He also found areas of overgrowth in the cervical spine.

Steinbach[82] was also unable to measure mandibular length. He found enlargement of sella in 22 of 27 patients. He also discovered occipital spurs in 12 of 19 cases. He concluded that under the influence of growth hormone in adults, bone growth as a result of periosteal apposition is more extensive than endochondral ossification. This appositional growth is found primarily in those bones or parts of bones where growth normally occurs throughout life. These spurs are commonly seen in cartilagenous joints and can be considered part of the normal growth or aging process. Acromegaly is simply an acceleration of this process.

The ability to remodel throughout life is an important mechanism for any joint. Articular cartilage helps the joint adapt to new and sometimes degenerate functional demands. This is in clear contrast to the cartilagenous growth plates of long bones or the synchondrosis in the craniofacial complex.[74] In spite of the different embryologic backgrounds the mandibular and occipital condyle have similar histologic appearance, in response to similar functional requirements.

The exact nature of the relationship between these two condyles has yet to be fully elucidated. Information regarding their response to mechanical, neural, and hormonal stimuli is still incomplete. Further research is needed in the area of cell differentiation, modulation, and ossification. Nevertheless, because of their similarity, it would seem appropriate to compare these structures when analyzing lateral radiographs.

If a correlation between the size of the condyles was obtained then perhaps a large occipital condyle would be used to "flag" a potential "overgrown" mandible. The occipital bone is one of the first areas of the cranium to ossify.[71] This is necessary to carry the weight of the head.[83] However, lengthening of the cranial base continues at the spheno-occipital synchondrosis.

Based on a study of dried skulls, Ford[84] has suggested that the cranial base overall grows in an intermediate fashion between the growth of the cranium, which is dependent on the neural pattern of early and rapid growth, and the face, which conforms to a general skeletal pattern characterized by fairly even growth from birth until the pubertal spurt. He emphasized that the individual parts of the cranial base manifest either a neural or general skeletal rate, not an intermediate one. The area between the foramen caecum and sella exhibit a neural pattern. Whereas the areas from nasion to the foramen caecum and from sella to basion follow the general skeletal growth rate. The growth in the latter two areas are due mainly to the frontal sinus and spheno-occipital synchondrosis respectively.

The occipital condyle is the first spinal articulation to ossify. The rest of the spinal cord completes ossification from the upper cervical vertebrae progressively downwards.[78] Further growth is endochordral and follows the general skeletal pattern. The exact timing of this growth has not been studied. Roche[85] has noted that late changes in cranial base dimensions appear as a growth spurt, which preceeds late mandibular growth. It would seem likely that the occipital condyle would follow a similar pattern. More quantitive study would be necessary to verify this proposal.

It has been difficult to compare biological relationship of the mandibular and occipital condyle. This is mainly due to the scarcity of information involving the development of the occipital articular cartilage. Gathering evidence to support this correlation has at times been like fitting a square peg into a round hole. Nevertheless, the accumulated information justifies a pilot study correlating mandibular prognathism with the height of the occipital condyle.

MATERIALS AND METHODS

The sample consisted of the pretreatment records of 83 patients from the Orthodontic and/or Oral Surgery Department of the Oregon Health Sciences University. The participants were predominantly Caucasians of Northern European ancestry and middle socio-economic class. The individuals were determined to be non-growing or nearly so, on the basis of age. The main criteria for acceptance into this study was the presence of an Angle Class II or Class III molar relationship in conjunction with a predetermined ANB angle. The cases were further selected according to the quality and completeness of each subject's lateral cephalogram.

The control group was comprised of 34 females and 10 males possessing Angle Class II molar relationships and an ANB angle of at least +3 degrees. The female control group ranged in age from 15 years, 10 months to 58 years, 11 months (mean age 28 years, seven months). The male control group ranged from 16 years, four months to 39 years, 10 months (mean age 26 years, five months). The size of the male control group was limited by the demands of the criteria previously set forth. It was felt that obtaining records from other sources (using a different operator and cephalometric apparatus) would introduce unnecessary errors. It was also apparent that the high quality of the radiographs taken at the Orthodontic Department could not be matched outside the school.

The experimental group consisted of 18 females and 21 males, all of which possessed an Angle Class III molar relationship and an ANB angle of 0 degrees or less. The female experimental group ranged in age from 14 years, eight months to 34 years, one month (mean age 25 years, one month). The male experimental group ranged from 15 years, 10 months to 39 years, four months (mean age 24 years, five months).

The data was derived from pretreatment lateral head radiographs taken with the same Broadbent-Bolton cephalometer. This instrument exhibits an enlargement of $\bar{x}$ = 7.8% Range 7.1 - 8.8%, which was uncorrected to facilitate the future use of the findings. All films were taken with the patient in centric occlusion by the same experienced radiographic technician. Several individuals were eliminated from this study because the radiographic exposure missed a measured landmark. Several others were dropped due to the poor quality of film development. However, films were not eliminated due to difficulty in landmark determination, since quantifying the ability to locate these points on typical films was deemed clinically useful.

The radiographs were traced onto an 8" x 10" sheet of acetate using routine techniques and the points S,N,A and B were identified. The angle ANB was then constructed and measured to the nearest 0.5^{o} for both the Class II and Class III groups. From this value it was determined whether a given individual was included in either the control or experimental sample.

Once the sample had been selected, mandibular length was measured in a manner used by Bjork[3] (Figure 4). First, articulare was located as explained in the Appendix. The point articulare was described by Bjork[3] as being more reliable than condylon and has been recommended by others[37,55,56] for use in evaluating mandibular length. A line was then extended from articulare to point dd, which Bjork described as the most prominent point of the chin in the direction of measurement. This length was then measured to the nearest 0.1 mm. Although there was a $\bar{x}$ = 7.8% enlargement, a correction factor was not included on any of the following computations.

The measurement of the vertical height of the occipital condyle was a more difficult problem. This was due to both the inability to always clearly discern the condyle, as well as finding a close stable reference plane. The ability to trace the condyle improves rapidly with practice. A common mistake for the neophyte is to outline the borders of the mastoid process. Nevertheless, with an excellent quality film and careful note of the bony contours, it is possible to reproduce the image consistently.

The location of a stable, reproducible reference plane which is located close to the occipital condyles can be obtained by using Frankel's[83] Occipital Reference Plane (Figure 4). This plane is constructed by first locating point 0', which is the intersection of the ventrocaudal contour of the occipital bone and the anterior outlines of the occipital condyles. A line is then extended backwards from 0' to point 0", which is the intersection of this line with the most inferior portion of the internal occipital (sagittal) ridge. The ease of locating this line is suprising to most first time tracers. The variability in the height of the internal occipital ridge and sometimes the difficulty in locating point 0' will be discussed later.

Once the occipital reference plane has been drawn, the occipital reference parallel plane is constructed. This plane is parallel to the initial occipital reference plane and intersects the most inferior point of the occipital condyle. The vertical height of the occipital condyle was then measured to the closest 0.1 mm on a perpendicular line connecting the two reference planes (Figure 4).

The mean, standard deviation, and standard error of the mean were calculated for both mandibular length and occipital condyle height in each sex of the control and experimental group. The males and females were then combined in each group and the mean, standard deviation, and standard error of the mean were calculated for both measurements in the mixed control and experimental samples. It was decided to combine the male and females in each group to obtain a $N = 30$. Since information on the variability of the occipital condyle was lacking a $N = 30$ eliminated the need for determination of a normal distribution and homogeneity of variance. This is based on the central limit theorem which states[86]:

> "If a population distribution of any shape has a mean ($\bar{x}$) and a standard deviation (S.D.), then the sampling distribution of sampling means computed on samples randomly drawn from this population will approach normal distribution with a mean ($\bar{x}$) and a standard error of SD N as N increases. When $N = 30$ this approximation to a normal distribution is usually sufficient to use standard Z(+) tables."

This approach is very conservative since the data for this study appears normally distributed on a scattergram. Nevertheless, since we have such a large sample it eliminates the need to check this distribution mathematically and allows us the ability to use the more powerful "Z" table.

The mean data was then analyzed for possible significant differences in the following manner. First, the differences in mean mandibular length were tested for significance using the Student's t-test. Then the difference in mean occipital condyle height was tested for significance using the Student's t-test. The null hypothesis was rejected where $p = 0.05$.

To obtain a greater difference in mean mandibular length, and thus hopefully mean occipital condyle height, the total sample was divided into the 30 largest and 30 smallest mandibles. These two groups were then handled in the exact manner as the original sample.

Finally, to quantify any positive correlations between the length of the mandible and the height of the occipital condyle a scattergram was constructed and a Pearson's r correlation coefficient was run on the entire sample.

There are two general classes of error which occur in the estimation of cranial dimensions.[62,63] The first involves "errors of projection". These result from the fact the head film is a two-dimensional shadow of a three-dimensional object.

Since the rays which produce the shadow are nonparallel and originate from a very small source, head films are always distorted enlargements, the enlargement factor varying with the plane at which the estimated point lies. To truly eliminate this source of error the location of landmarks has to be known in three dimensions. This has not been a practical solution for the clinical orthodontist. Perhaps the most practical method of reducing this type of error is to use a standardized technique utilizing the same equipment and selecting landmarks close to the mid-sagittal plane. This would help to eliminate rotation effects as well as differential enlargement. Errors in subject positioning would hopefully cancel each other out with a standardized method.

The second general class of errors in head film measurement are "errors of identification". These involve errors in landmark location as well as tracing and measurement error. Baumrind[63] has noted that the latter are very real but conceptually trivial. He concluded that with the use of computers this type of error could be almost totally eliminated. Since the present study was completed without the aid of computers, the estimation of "error of identification" includes these factors.

A double determination was performed to evaluate this inherent error. Thirty randomly chosen lateral cephalograms were retraced by the same investigator one week after the original tracing. The standard error of the measure was determined for both mandibular length and occipital height using the formula.[2]

$$\text{S.E. Meas.} = \sqrt{\frac{d^2}{N}}$$

where:

d = Difference between duplicate measurements.
N - Number of scores.

It should be noted that mistakes in radiographic technique could be a major source of error. Image blurring from motion, the pneumbra effect, jaw positioning, film and screen selection, and especially poor darkroom procedures could introduce major problems in radiographic interpretation. These difficulties were reduced in this study by selecting excellent quality films.

RESULTS

The findings and statistical results are presented in Tables III through VII.

Table III provides the mean and standard deviation for the age, ANB angle, mandibular length, and occipital height for each sex of the Class II and Class III sample. The standard error of the mean was also given for mandibular length and occipital condyle height. The standard error of the mean was not calculated for the age or ANB angle since these were just arbitrary values from sample selection. However, the standard error of the mean was useful for metric values since it gave a range above and below the sample mean within which the mean of the population lies. This gave the potential error that may have been included in the size and variability of the sample in relation to the entire population.[87]

Table IV indicates the mean and standard deviation for age, ANB angle, mandibular length and occipital condyle height for the combined Class II and Class III sample. Again, the standard error of the mean was given for the quantitative data only. The difference in mean mandibular lengths was significant at $p = 0.01$. Conversely, the difference in mean occipital condyle height was not significant.

Table V presents the same data as Table IV on a sample of the 30 largest versus the 30 smallest mandibles regardless of sex. The mean difference in mandibular length was significant at $p = 0.01$, whereas again, the mean difference in occipital condyle height was not.

Table VI documents the values for the Pearson's r correlation coefficient. This value of $4 = 0.067$ was found to be not significant for the entire sample.

Table VII compares the standard error of the measure for mandibular length (S.E.Meas. = 0.36 mm) and for occipital condyle height (S.E.Meas. = 0.54 mm).

DISCUSSION

The purpose of this paper was to explore the possible correlation between mandibular length and the height of the occipital condyle. The discussion of this relationship is limited by the almost complete lack positive results. Perhaps reviewing the literature of growth prediction would prepare one for the futility and limitations in such a study. In spite of this a review of anatomic, embryologic and histologic findings gave a reason to proceed onwards. This, in conjunction with the almost total lack of research into the size of the occipital condyle, gave hope (however limited) that the prediction of mandibular growth could be forecast.

The examination of Table III reveals mandibular lengths similar to those reported earlier. Bjork[3] measured the mandibular length of 281 Swedish male conscripts past the age of 21 but not 23 in the same manner as the present study. He found a mean length of 118.45 mm, S.D. 6.28 mm, and S.E.Meas. 0.37 mm, which was very similar to this sample. McNamara[27] reviewed the Ann Arbor, Bolton Standards and Burlington Centre material and found mandibular length to be generally five to 10 mm. longer. This difference is due to the method of measuring mandibular length from condylon to gnathion instead of articulare to the most prominent point on the chin. Guyer[37] and Jacobsen[19] reported similar results. It should be noted that mean male mandibular lengths always showed a higher degree of variability.

The most striking result tabulated in Table III is the similarity in mean occipital condyle heights of about 11 mm. This small difference in mean heights will be discussed shortly. This height is similar to that found by Olivier[4] on occipital bone autopsy specimens. He found mean height in a mixed sample of 116 bones to be 8.80 mm S.D. 1.37 measured on a perpendicular from the basion-opisthion plane. The present study reports a somewhat longer height due to the higher reference plane and perhaps as a result of radiographic enlargement.

Table IV reports the mean differences in mandibular length for a Class II and Class III sample to be significant (p = 0.01). These findings have been noted by others[3,19,29,30,31,32,37]. As mentioned above, the small difference in mean occipital condyle height is surprising. Because of the nature of the part-whole correlation, it was suspected that a large jaw might have a large head, and also large occipital condyles. Apparently, the size of these two structures is almost completely independent. It should be noted that the Class III sample does show greater variability in both dimensions measured.

To create a greater difference in mean mandibular length, the total sample was divided into the 30 largest and 30 smallest mandibles. Again, there was a significant difference in the mean mandibular length and an insignificant difference in occipital condyle height as noted in Table V.

To quantify the degree of correlation between mandibular length and occipital condyle height, a Pearson's r correlation coefficient was run on the entire sample as shown in Table VI. The value of r = 0.067 might have been suspected from the scattergram. This value was not significant and obviously not predictive. This is extremely low when compared to other size-size correlations of the head which vary between r = 0 to r = 0.6, with many greater than r = 0.3. This again is due to the effect of the part-whole correlation.[2,4] These findings show mandibular length to be independent of occipital condyle height.

The potential sources of error in radiographic studies were discussed earlier. The accuracy in landmark location is summarized in Table VII. It reports the standard error of the measure for mandibular length to be S.E.Meas. 0.36 mm. This was almost exactly the same as Bjork (S.E.Meas. 0.37 mm.) obtained using the same technique. This would have been even lower if several extreme values had been eliminated. Others[19,37] have reported greater error when utilizing condylon as the posterior reference point. These values are consistent with Baumrind's[62,63] magnitude of error in locating articulare.

The standard error of the measure for the occipital condyle height was 0.54 mm. This also may have been less if several extreme differences had been remeasured. There were three main difficulties in obtaining this measurement. First, sometimes point 0' was on such a gradual curve that it was difficult to distinguish the basilar part of the occipital bone from the condyles. Next, the mastoid process was easily mistaken for the condyle. Finally, the height of the internal occipital ridge varied greatly from person to person. Although this had no effect on measurement error, it increased the variability in actual occipital condyle height.

In general, the accuracy in landmark location and measurement ability was felt to be acceptable. The reliability of this actually measuring condylar height may be suspect due to the variability of the occipital reference plane. Nevertheless, with total mean differences in the same magnitude as the standard error of the measure the validity of this whole project is in question. If the mean differences had been larger, this information would be more useful. With these small differences, the statistical treatment became just a mathematical exercise. Perhaps with such a small structure as the occipital condyle, the small mean differences should have been anticipated; one never knows for sure until it has been quantified.

SUMMARY

This study established normative data for occipital condyle height in a sample of non-growing male and female individuals with both Angle Class II and Class III molar occlusion and specific ANB requirements. The usage and limitations of this data was discussed with reference to the norm concept, statistical methodology, and error analysis.

The correlation of occipital condyle height with mandibular length was found to be almost totally independent. The validity of these results was questioned in relation to the measurement error.

The importance of late mandibular growth stimulated interest in predicting these changes. This paper again supported the futility in using radiographic methodology. Further understanding in genetic, hormonal and neural control of bone formation and growth will be necessary to truly understand and possibly predict this development. This "biologic" approach avoids the pitfalls of individual variation limiting our predictive powers. Until then, the best estimate of a child's adult size will be to add mean growth changes[42] (perhaps with the help of an archangel).

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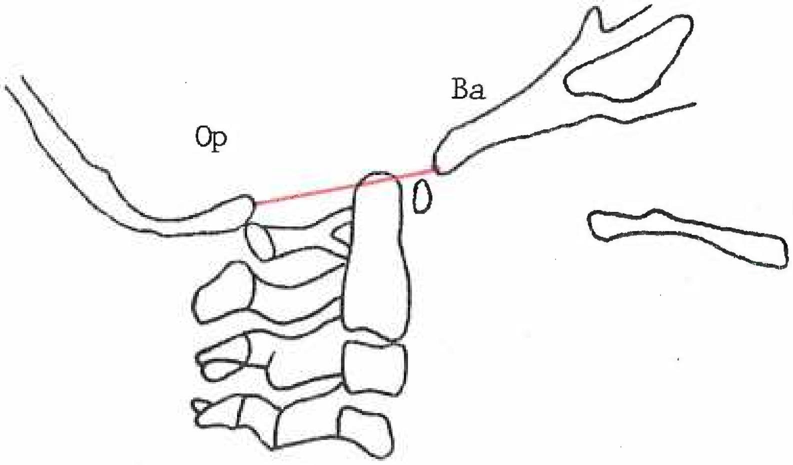
FIGURE I

McRae's Line

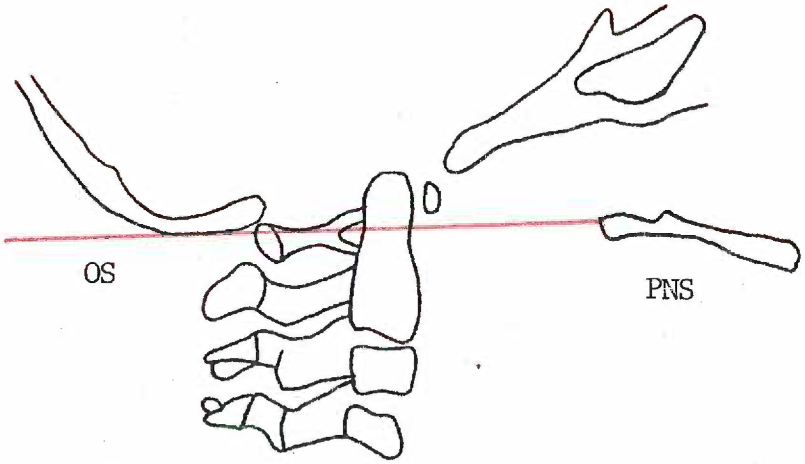


Ba = Basion

Op = Opisthion

FIGURE II

McGregor's Base Line

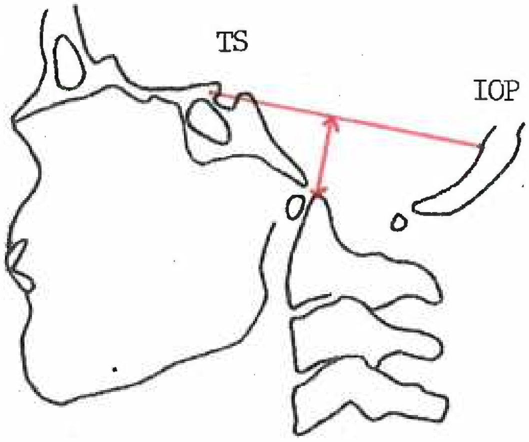


PNS = Posterior Nasal Spine

OS = Inferior Border of Occipital Squama

FIGURE III

Height Index of Klaus

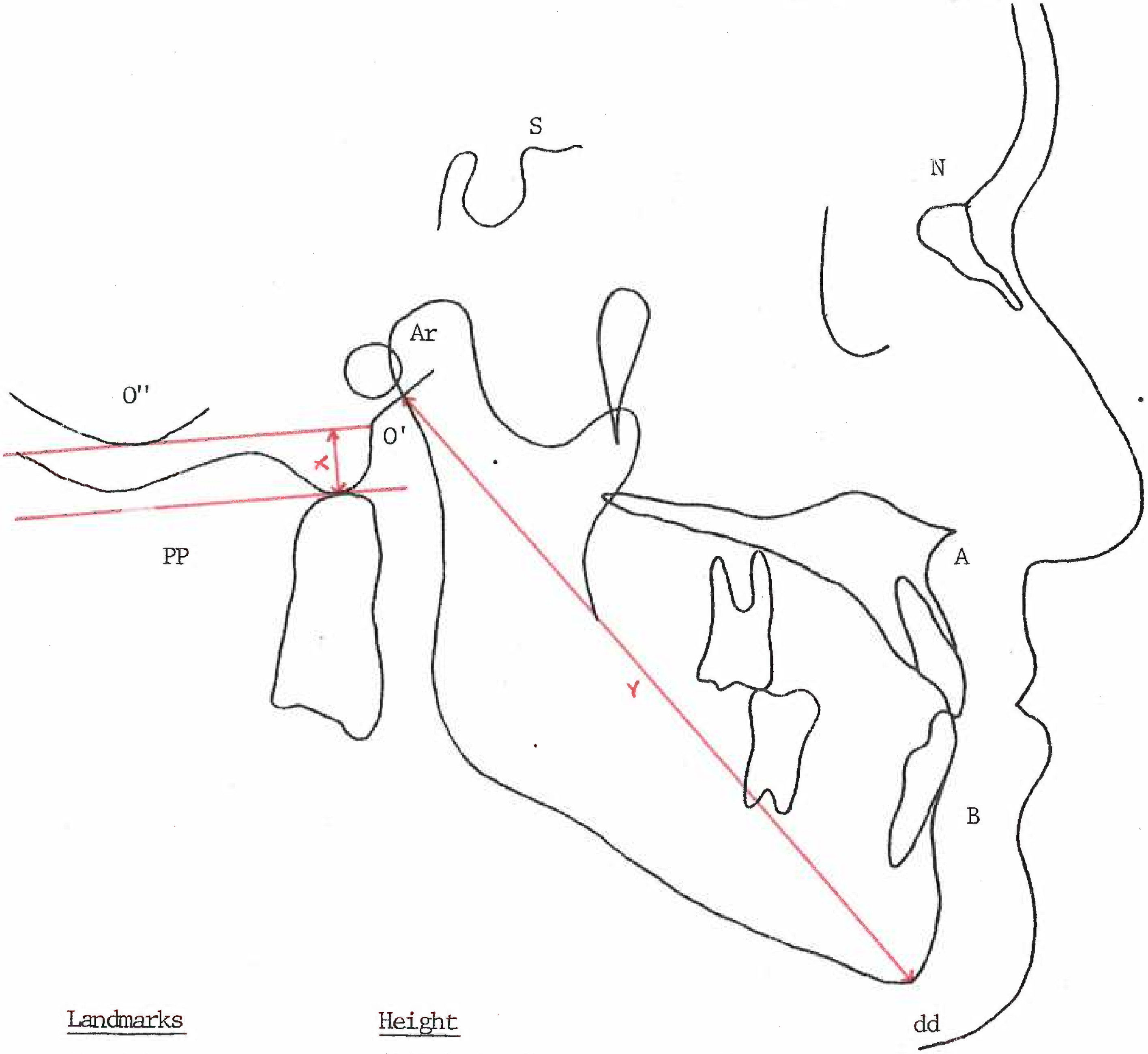


TS = Tuberculum Sella

IOP = Internal Occipital Protuberance

FIGURE IV

Sample Tracing Revealing Landmarks, Planes, Angles, Height, and Length.



Landmarks

S	Sella
N	Nasion
A	A Point
B	B Point
O'	O' Point
O''	O'' Point

Planes

S-N	SN Plane
O'-O''	Occipital Reference Plane
PP	Occipital Reference Parallel Plane

Height

X Height of Occipital Condyle

Length

Y Length of Mandible

Angle

ANB ANB Angle

TABLE I

Dimensions of Occipital Condyles (mm)[14]

	MALES			FEMALES					
	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.
Height	65	9.09	1.53	49	8.41	1.05	116	8.80	1.37
Length	65	24.51	2.56	51	22.74	2.70	118	23.75	2.74
Breadth	66	11.84	1.17	51	11.07	1.13	119	11.50	1.20

TABLE II

Mean Mandibular Length (mm) Measured from Condylon to Gnathion

	N	Sex	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1984 Ann Arbor Sample	38	Males					134.3	6.8
of Young Adults	73	Females					120.2	5.3
Bottom Standards	16	Males	126.8	4.7				
	16	Females	120.0	3.4				
	16	Males			131.0	4.6		
	16	Females			121.6	4.5		
Burlington Centre	50	Males	124.5	5.97				
	54	Females	117.7	4.5				
	17	Males			127.2	6.0		
	22	Females			118.9	4.7		
	38	Males					128.2	4.2
	44	Females					116.8	7.3

TABLE III
SAMPLE DATA

N	Sex	Angle	Age (Years)			ANB (Degrees)			Mandibular Length (mm)			Occipital Condyle Height (mm)		
			$\bar{x}$	S.D.	S.E.M.	$\bar{x}$	S.D.	S.E.M.	$\bar{x}$	S.D.	S.E.M.	$\bar{x}$	S.D.	S.E.M.
34	Female	Class II	28.60	9.22	1.58	6.60	2.11	0.36	105.56	5.32	0.91	10.88	1.40	0.24
10	Male	Class II	26.38	7.93	2.64	5.05	0.96	0.32	117.36	7.53	2.51	11.02	1.45	0.48
18	Female	Class III	25.05	7.13	1.73	-2.53	1.64	0.40	115.18	5.86	1.42	10.93	1.99	0.48
21	Male	Class III	24.40	7.61	1.70	-3.36	2.17	0.49	128.37	6.34	1.42	11.54	1.82	0.41

N = Number included in Sample

Angle = Angle Molar Classification

$\bar{x}$ = Mean

S.D. = Standard Deviation

S.E.M. = Standard Error of the Mean

TABLE IV

Correlation of Mean Mandibular Lengths and Mean Occipital Condyle Heights in an Angle Class II and Class III Sample.

		Age (Years)		ANB (Degrees)		Mandibular Length (mm)		Occipital Condyle Height(mm)	
N	Angle	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
39	Class III	24.70	7.30	-2.97	1.96	122.28	8.99	11.26	1.90
44	Class II	28.10	8.90	6.25	2.01	**108.25	7.66	N.S. 10.92	1.40

N = Number included in sample.

Angle = Angle molar classification

$\bar{x}$ = Mean

S.D. = Standard Deviation

** = Significant at 0.01 Probablility Level.

TABLE V

Correlation of Mean Mandibular Lengths and Mean Occipital Condyle Heights in a Sample of the 30 Largest and 30 Smallest Mandibles.

		Age (Years)		ANB (Degrees)		Mandibular Length (mm)		Occipital Condyle Heights (mm)	
N	Size	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
30	Largest	24.72	7.40	-2.31	3.39	126.79	6.18	10.91	1.41
						**		N.S.	
30	Smallest	27.38	7.82	6.00	3.17	103.87	4.00	11.31	1.79

N = Number included in Sample

$\bar{x}$ = Mean

S.D. = Standard Deviation

** = Significant at 0.01 Probability Level

TABLE VI

Pearson's r Correlation Coefficient Comparing Mean Mandibular Length to Mean Occipital Conyle Height in the Total Sample of N = 83.

$r = 0.067$ N.S.

TABLE VII

Standard Error of the Measure for Mandibular Length and Occipital Condyle Height Calculated from 30 Repeated Measures.

Mandibular Length S.E.Meas. = 0.36 mm.

Occipital Condyle Height S.E.Meas. = 0.54 mm.

APPENDIX

The following is a list of the skeletal landmarks, construction points and linear and angular measurements utilized in this study:

Skeletal Landmarks

1. S - Sella turcica - The midpoint of sella turcica, determined by inspection.
2. N - Nasion - The intersection of the internasal suture with the naso-frontal suture in the midsagittal plane.
3. A - A Point - The deepest point on the maxillary midline between the anterior nasal spine and prosthion.
4. B - B Point - The deepest midline point on the mandible between infradentale and pognonion.
5. Ar - Articulare - The point of intersection of the dorsal surface of processus articularis mandible and os temperale. The midpoint A is used where double projection gives rise to images, A1 and A2.

Construction Points and Planes

1. dd - dd Point - The most prominent point of the chin in the direction of measurement.
2. 0' - 0' Point - The intersection of the ventrocaudal contour of the occipital condyles.
3. 0" - 0" Point - The intersection of the most interior portion of the internal occipital (sagittal) ridge with a line drawn from 0' point.
4. 0'0" - Occipital reference plane.

5. O'O" - Occipital reference parallel plane - The plane which is parallel to the occipital reference plane and intersects the most interior point of the occipital condyle.
6. SN - Sella nasion plane.

Angular and Linear Measurements

1. SNA - The angle formed by connecting points S, N, and A.
2. SNB - The angle formed by connecting points S, N, and B.
3. ANB - The angle formed by connecting points A, B, and B.
4. Ar - dd - The linear distance from articulare to the most prominent point of the chin in the direction of measurement.
5. Height of occipital condyle - The perpendicular linear distance between the occipital reference plane and its parallel plane.